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Harnessing Ocean Energy by Tidal Current Technologies

Nasir Mehmood, Zhang Liang and Jawad Khan
College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 150001, China

Abstract: The world is heavily dependent on fossil fuels since most of its energy requirements are fulfilled by conventional methods of burning these fuels. The energy demand is increasing by day with growing population. The energy production by fossil fuels is devastating the environment and survival of life on globe is endangered. The renewal energy technologies are vital to ensure future energy sustenance and environmental issues. Ocean is a vast resource of renewable energy. The technology today makes it possible to extract energy from tides. The growing interest in exploring tidal current technologies has compelling reasons such as security and diversity of supply, intermittent but predictable and limited social and environmental impacts. The purpose of this study is to present a comprehensive review of tidal current technologies to harness ocean energy. The ocean energy resources are presented. The author discusses tidal energy technologies. The tidal current turbines are discussed in detail. The author reviews today's popular tidal current technologies. The present status of ocean energy development is also reported.

Keywords: Diffuser augmented tidal current turbine, open/naked turbine, shrouded/ducted turbine, tidal current device, tidal current turbine, tidal energy

INTRODUCTION

International Energy Outlook (IEO) study shows that most of the world's energy requirement has always been fulfilled by fossil fuels. Among fossil fuels, liquid fuels are major energy source as shown in Fig. 1 (Doman, 2010). The energy demand is increasing with growing population, thus, mounting burden on fossil fuel reserves (Bilgen *et al*., 2008). It is therefore a matter of deep concern that these reserves will run out in coming years. The extent of dependence on fossil fuels is alarming. The future energy substance is a serious concern for global community.

The prices of liquid fuels have been rising and expected to continue rising in future as shown in Fig. 2. The liquids share of world marketed energy consumption is projected to fall from 35% in 2007 to 30% in 2035 due to inflation in liquid fuel prices (Doman *et al*., 2010). Immense dependence on fossil fuel not only augments the issues like security of supply, it also harms the environment. Fossil fuels are the main source of anthropogenic emissions of CO_2 as shown in Fig. 3 (Doman *et al*., 2010). As a result, global temperature is increasing since the heat from sun cannot be radiated back into space due to Green House Effect caused by CO_2. Green House Effect is responsible for rise of sea level and climate change.

To address the issues of alarming dependence on fossil fuels, security of supply and environment, it is vital to use alternate energy assets (Carley, 2009).

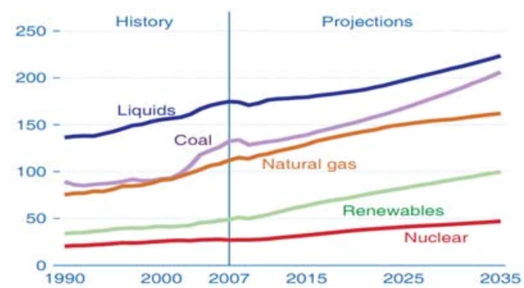

Fig. 1: World energy consumption by fuel type (Doman *et al*., 2010)

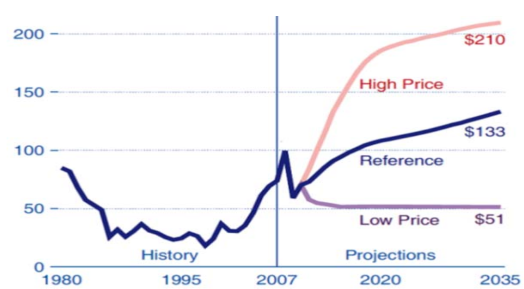

Fig. 2: Oil prices in USD per barrel (Doman *et al*., 2010)

Ideally, the alternate energy source should have minimum environmental effect and be renewable. Consequently, the renewable energy resources have

Corresponding Author: Nasir Mehmood, College of Shipbuilding Engineering, Harbin Engineering University, Harbin, 50001, China

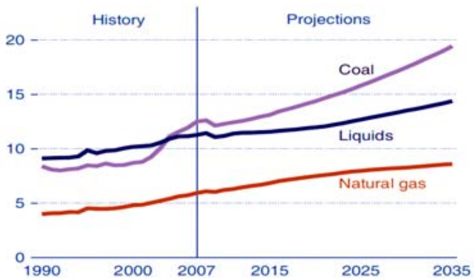

Fig. 3: Global CO_2 emission by fuel type (Doman *et al*., 2010)

acquired enormous attention in recent years as an alternate to fossil fuel to provide sustainable power production in the future. Renewable energy broadly includes wind, solar, hydro, biomass and geothermal energies. Wind and solar energies are considerably matured and widely used today.

Oceans, covering more than 70% of the earth's surface, are great resources of unexplored energy. The technologies that explore enormous and consistent untapped resources of ocean energy are referred as ocean power. Ocean power is mainly categorized as tidal power, wave power and thermal energy conversion systems. The idea of utilizing ocean energy is very old. One of the earliest patents was registered by a Frenchman and his son Girard in 1799 (Charlier and Justus, 1993). In 1980, more than a thousand patents were registered for converting wave energy into power (Michael, 1981). Research on wave energy is underway around the globe (Setoguchi *et al*., 1993; Setoguchi *et al*., 2001; Vijayakrishna *et al*., 2004) and the technology has been tested in many countries (Korde, 1991; Osawa *et al*., 2002; Clement *et al*., 2002).

Tidal power, also referred as tidal energy, is a wide source of consistent energy (Cave and Evans, 1984). Tidal energy technologies include tidal barrages, tidal fence and tidal current technologies. Present efforts are focused on tidal current technologies that utilize the kinetic energy of tidal currents (Steele *et al*., 2009). The growing interest in exploring tidal current technologies has many compelling reasons such as environment friendly nature, intermittent but predictable, security and diversity of supply and limited social and environmental impacts. Tidal current technologies are still in development phase and need some time to mature to prove their full potential.

This study discusses the necessity of renewal energy to ensure future energy security and address environmental issues. Ocean energy is a wide source of untapped renewable energy. Tidal energy, type of ocean energy, can be extracted by modern devices. The author undertakes in-depth review of harnessing ocean energy

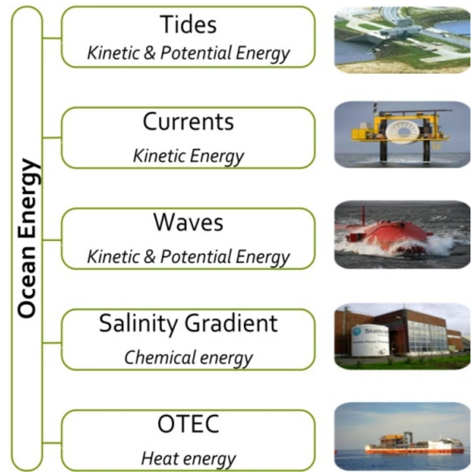

Fig. 4: Classification of ocean energy

by tidal current technologies. The ocean energy resources and tidal energy technologies are discussed. Today's popular tidal current technologies are presented. The author also reports present status of ocean energy development.

OCEAN ENERGY RESOURCES

Ocean energy is a kind of hydro energy. Ocean energy, an embryonic energy solution, has enormous potential for energy production in future. Ocean energy technologies are relatively new and applications are developing at very fast pace. As a result, concrete boundaries for classification, applications and conversion concepts have yet to be defined. This section is devoted to presenting these issues keeping in view available literature and current industrial trends.

Ocean energy can be tapped in multiple forms such as energy from waves, kinetic energy from tidal and marine currents, potential energy from tides and energy from salinity and thermal gradient. So we can classify the ocean energy on the basis of resources such as tides, currents, waves, salinity gradient and Ocean Thermal Energy Conversion (OTEC) systems as shown in Fig. 4.

Tides: Energy from tides is mainly captured during the rise and fall of the sea level. This rise and fall is due to the interaction of gravitational pull in earth, moon and sun system. The tide comprises of vertical water movement (rise and fall) and horizontal water movement (tidal current). The tidal range and tidal current have often been confused in literature in past. The difference between tidal range and tidal current is that tidal range is the difference between high and low tide (potential energy) whereas tidal current is the horizontal water movement (kinetic energy). Annapolis Tidal Power Plant, one of first three tidal power plants in the world, came online in 1984. It has a capacity of 20 megawatts (Bregman *et al*., 1995).

Currents: Currents are generated not only by tides but also by wind, temperature and salinity differences. The concept of tapping kinetic energy from ocean currents is the same as tidal currents. The marine and tidal current technologies share same principles of operation.

Waves: The research work to generate electricity from ocean waves is also under immense focus. Pelamis Wave Power is one of the devices that capture wave energy to generate power (Pelamis Wave Power, 2011).

Salinity gradient: The research on extracting power from salinity gradient is in early phase. The devices are installed on several locations around the globe but most are experimental. Due to limitation of space and focus of this study on tidal current technologies, only few methods for salinity gradient applications are mentioned here. There are four popular methods to extract energy from salinity gradient named Solar Pond, Pressure-Retarded Osmosis, Reversed Electrodialysis or Reverse Dialysis and DorianoBrogioli's capacitive method. DorianoBrogioli's capacitive method is relatively new and has so far only been tested on lab scale. Statkraft opened a prototype osmotic power plant in Norway in Nov 2009 (Gerstandt *et al*., 2008).

Ocean thermal energy conversion: Ocean Thermal Energy Conversion (OTEC) technologies make use of heat engine which uses the temperature difference between cold and hot water. Due to heat from sun, the water is warmer on top and gets cooler as depth increases. The conditions for OTEC are most promising when the temperature difference between hot and cold water is 20^{O}C. These conditions are found near equator. The efficiency of heat engine increases with increase in temperature difference. OTEC is still an emerging technology. Sagar-Shakthi is a closed cycle OTEC plant with a capacity of 1 MW in India (Magesh, 2010).

TIDAL ENERGY TECHNOLOGIES

The detailed classification of tidal energy technologies and tidal current technologies is shown in Fig. 5. Since the focus of this study is tidal current technologies, these technologies/devices are presented in detail.

Tidal current technologies utilize devices that convert the kinetic energy of currents to electric power. Tidal current devices are analogous to wind energy

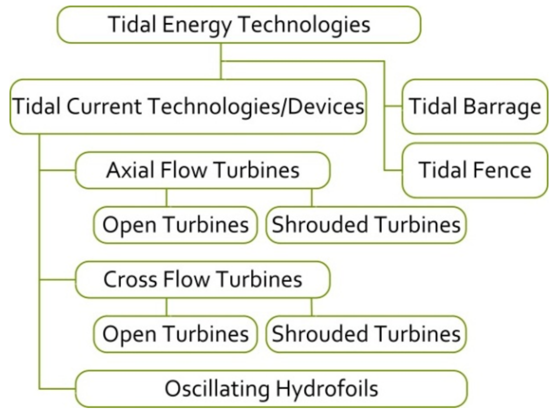

Fig. 5: Classification of tidal energy

devices (Rourke *et al*., 2009). However differences exist since water is 832 times denser than air whereas its flow speed is slower than air (Bryden *et al*., 2004). The tidal current devices function under water, hence, these devices are subjected to higher structural loads than wind turbines. The tidal current devices must survive the extreme structural loads and have capability to generate power during both flood and ebb tides

Axial flow turbines: Axial flow turbines, also known as horizontal axis turbines, can either be shrouded (ducted) or open (naked). Axial flow turbines typically have two or three blades riding on a rotor which is oriented in the direction of flow. The axis of rotation is parallel to incoming water stream. The lift type blades are used to rotate the generator for producing power. In shrouded turbines, the concept is to accelerate the velocity of incoming flow by using a special shape.

Cross flow turbines: Cross flow turbines, also known as vertical axis turbines, can also either be shrouded (ducted) or open (naked). Cross flow turbines typically have two or three blades riding on a vertical shaft which forms a rotor. The axis of rotation is perpendicular to incoming water stream. The incoming flow creates lift force to drive rotor, rotor then rotates the generator for producing power. The shroud concept is same as axial flow turbines where special shape is used to increase the velocity of incoming flow.

Oscillating hydrofoil/reciprocating devices: Instead of using the rotational drive of turbine, it is also possible to capture tidal energy by using an oscillating hydrofoil. These devices make use of the lift/drag forces of the wing like hydroplane to move up and down. This mechanical energy is converted to electrical energy. Oscillating motion is controlled by changing the angle of attack relative to incoming water.

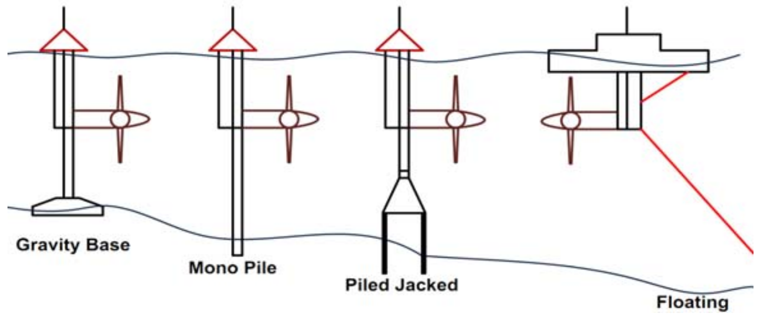

Fig. 6: Different kinds of support structures (Snodin, 2001)

COMPARISON OF SHROUDED (DUCTED) AND OPEN (NAKED/UN-DUCTED) TURBINE

The tidal current turbine industry used open turbines before but now there is an increasing shift towards shrouded turbines. The reason is the higher power output of shrouded turbines. However, this higher power output comes at some cost. The relative advantages and challenges of shrouded turbine compared to open turbine are listed below.

Advantages:

- Shrouded turbines extract more energy than open turbines. Shrouded turbines are more efficient due to flow manipulation and tip losses elimination. Shrouded turbines are smaller in size for the same power.
- Shrouded turbines are quieter than conventional open turbines.
- Shrouds are useful against weed growth as they protect the turbine against sunlight.
- Shrouds provide safety against floating debris and divers.
- Shrouded turbine provides more design flexibility since torque on main power shaft can be eliminated. It is materialized by installing magnet on blades and incorporating stator windings in ducts. Thus the blade also acts as rotor of a permanent magnet generator. This eliminates the need of gearbox as well as torque on main shaft, thus, reducing mechanical parts and increasing efficiency.
- Shrouds can be made with low cost materials. The present efficiency to cost ratio of shrouded turbines will further increase with increasing use of low cost materials in shroud fabrication.

Challenges:

- To achieve high efficiency, small clearance is required between shroud and blade tip. This requires fabrication and assembly of very complex shapes with very low tolerances which is both expensive and complicated.
- The inner and outer profiles of shrouds themselves can be quite complex to fabricate.
- Shrouded turbines operate at higher RPM which gives rise to vibration issues.
- Shrouded turbines have more drag than open turbines and require additional support structure.

TIDAL CURRENT TURBINE COMPONENTS

The typical tidal current turbine has following components:

- Tidal turbines can have two or more blades mounted on a hub, together known as rotor. The fluid flow over blades creates forces to rotate the rotor.
- Rotor is connected to a power shaft which transmits torque.
- Power shaft is connected to a gearbox which is used to get the required RPM from power shaft.
- Torque at required RPM is then transmitted to a generator to produce power.
- The power is then transmitted to land with the help of underwater cables.
- All the parts are enclosed in a watertight capsule called nacelle, like in wind turbine technology. Nacelle is then mounted on support structure which bears the loads in harsh marine environment.

Support structure for tidal current turbine: Choosing a suitable support structure depends on size of turbine, water depth and seabed soil conditions. Gravity, piled or floating support structures are most commonly used for tidal current turbines, shown in Fig. 6 (Snodin, 2001). In gravity support structure, large steel or concrete block is attached to the turbine and placed on sea bed. The gravity

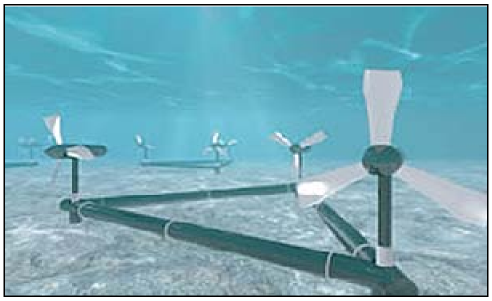

Fig. 7: Deltastream turbine (Tidal Energy Ltd, 2011)

Fig. 9: Free flow turbine (Verdant Power, 2011)

Fig. 8: Evopod tidal turbine (Oceanflow Energy, 2011)

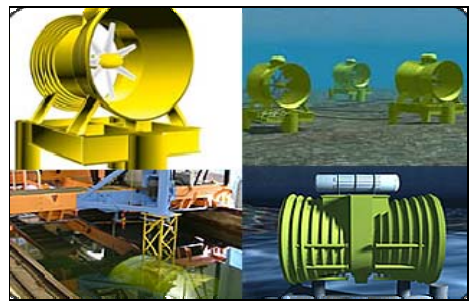

Fig. 10: Rotech tidal turbine (Lunar Energy Ltd, 2011)

support structure is very stable. In piled support structures, one or two, steel or concrete pillars are used for holding the turbine. In floating support structures, the turbine is secured at bottom of floating platform and also secured to seabed by wires/chains.

POPULAR TIDAL CURRENT TECHNOLOGIES

Deltastream turbine: Deltastream Turbine (Fig. 7) is developed by Tidal Energy Ltd (2011) based in Cardiff, Wales, UK. The company is funded by ECO2 and Carbon Connections. The 1.2 MW device developed by Tidal Energy Ltd (2011) consists of three, three-bladed horizontal axis turbines. The diameter of each turbine is 15 m. The device is mounted on a triangular frame and has low center of gravity for stability (Tidal Energy Ltd, 2011).

Evopod tidal turbine: Oceanflow Energy is extensively involved with horizontal axis turbine technologies. Oceanflow Energy is currently involved with 35 kW Evopod. This version is based on a scaled up version of the unit, which was successfully tested in Strangford Narrows as shown in Fig. 8. A 55 kW version of the same unit can be developed for sites with faster flow. The 55 kW version will be grid connected for heating or electricity (Oceanflow Energy, 2011).

Oceanflow Energy is also involved with a twin-turbine version of its Evopod. The 1/40th scale model was tested in Newcastle University. The unit would be fitted with twin 1.2 MW generators at full scale. Each generator would be coupled to a three-bladed turbine of 16 m diameter. The unit would be capable of generating 2.4 MW for flow speeds of 3.2 m/s and above (Oceanflow Energy, 2011).

Free flow turbine: Free flow turbine (Fig. 9) is developed by Verdant Power (2011) based in United States. It is a three bladed horizontal axis turbine, with 5 meter diameter. Company completed successful demonstration of full system in East River near New York City. It has already generated 70 MW/H of energy and completed 9,000 turbine hours. (Verdant Power, 2011).

Rotech Tidal Turbine (RTT): RTT (Fig. 10) is developed by Lunar Energy Ltd (2011) based in UK. It is a 1 MW horizontal axis bi-directional turbine enclosed in a symmetrical venturi duct. Turbine diameter is 15 m, with duct length of 19.2 m. RTT captures the energy in ocean currents and converts this energy to electricity by venturi effect. RTT has a gravity foundation which makes it rapidly deployable with almost no seabed preparation at depths greater than 40 m. RTT also has a size advantage since it is 5 times in size compared to other turbines units using pile foundations. The dry

Fig. 11: Nereus and solon tidal turbines (Atlantis Resources Corporation Ltd, 2011)

testing of 1 MW lunar generation unit was successfully completed in 2008 (Lunar Energy Ltd. 2011).

Nereus and solon tidal turbines: Nereus and Solon tidal turbines (Fig. 11) are developed by Atlantis Resources Corporation Ltd (2011) based in Singapore, previously based in Australia. Atlantis became one of the first companies in the world to link a tidal turbine to a national grid in September 2006. Atlantis accomplished this by installing a 100 kW Aquanator device in San Remo, Victoria, Australia (Atlantis Resources Corporation Ltd., 2011).

Atlantis tested its Nereus-I, a horizontal axis 100 kW 30 ton turbine unit, in open water in December 2007. It was followed by a 150 kW Nereus-I, presently known as AN-150, connected to grid and commissioned in May 2008 at San Remo, Victoria, Australia. Soon followed by Nereus-II, presently known as AN-400, tidal current turbine tow tested in open ocean in July 2008, which broke previous records by clear margin. Atlantis, AN series horizontal axis turbine is designed for shallow water. AN-400 uses Aquafoils to capture the water flow momentum to drive a chain perpendicular to the flow. AN-400 was successfully tested in 2008. AN series has been extensively tested and linked to grid in Australia (Atlantis Resources Corporation Ltd., 2011).

In 2008, Atlantis launched Solon (AS) series horizontal axis turbines for rivers and durational tidal locations. The AS-500 was tested in Singaporean waters. The AS series is rated at 2.6 m/s and available in 100 and 500 kW and 1 MW versions (Atlantis Resources Corporation Ltd., 2011).

Atlantis, AK series horizontal axis turbine is designed for challenging open ocean environment. AK turbines are installed with twin rotor set with fixed pitch blades. AK series is rated at 2.6 m/s and available in 1 and 2 MW versions (Atlantis Resources Corporation Ltd., 2011).

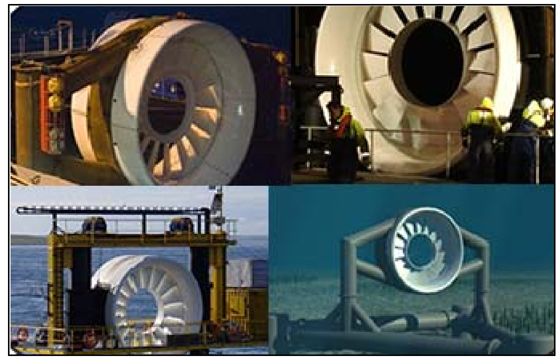

Fig. 12: Open centre turbine (Open Hydro Ltd, 2011)

Fig. 13: Seagen turbine (Marine Current Turbines Ltd, 2011)

Open centre turbine: Open-Centre turbine (Fig. 12) is developed by Open Hydro Ltd (2011) based in Ireland. Open-Centre turbine is a horizontal axis turbine, consisting of 6 m diameter rotor, a stator, a duct and a generator. Open Hydro Ltd was one of the first tidal current energy company to link to the UK national grid for power generation. Open Hydro Ltd was also awarded a contract to develop a demonstration farm in France in 2008. Open Hydro successfully deployed the first 1 MW commercial scale in-stream tidal turbine in Canada in 2009 (Open Hydro Ltd., 2011).

SeaGen: SeaGen tidal turbine (Fig. 13) is developed by Marine Current Turbines Ltd., (2011) based in UK. SeaGen is a 1.2 MW horizontal axis turbine with 16 m diameter twin rotor. Rotor is connected to a gearbox to increase shaft's rotational speed to drive a generator. The controllable pitch rotor blades allow function in both ebb and flood tides. SeaGen 1.2 MW unit was made operational in January 2009 (Marine Current Turbines Ltd., 2011).

Tidal stream turbine: Tidal stream turbine (Fig. 14) is developed by Hammerfest Strom (2011) based in UK. Hammerfest Storm devices are three bladed horizontal

Fig. 14: Open centre turbine (Hammerfest Strom, 2011)

Fig. 15: Underwater electric kite (UEK Corporation Ltd., 2011)

axis tidal current turbines. Hammerfest Storm started its work with HS300, which was world's first tidal current device connected to grid in UK in 2003. HS300 remained in service for four years and provided both power and valuable knowledge (Hammerfest Strom, 2011). This knowledge has played a key role in improvement of tidal current technologies.

Hammerfest Storm's efforts and experience gained with HS300 brought forth the pre commercial HS1000, a 1 MW unit. HS1000 is capable of producing power in both directions of water flow. Nacelle stays fixed while the turbine blades rotate around their axis. Automated control permits unmanned operations and higher output. The device is mounted on a gravity foundation with tilted support structure. Gravity based foundation requires minimal installation resources and tilted support structure reduces structural vibrations (Hammerfest Strom, 2011).

Underwater Electric Kit (UEK): UEK (Fig. 15) is developed by UEK Corporation Ltd (2011) based in USA. UEK is a horizontal axis, 3.3 m rotor diameter, dual hydroturbine system. The system is capable of operating as single unit or in connection with grid. UEK can be installed in free flow on surface or bottom of the river. The system is designed for optimum output at velocities of 2 to 4 m/s, providing 75 kW at 2 m/s. UEK Corporation Ltd has two projects underway, one in Yukon River in Alaska and second in Indian River. Yukon River project is a 100 kW system whereas Indian River tidal power plant is 25 twin UEK system (UEK Corporation Ltd, 2011).

Fig. 16: Tocardo aqua turbine (Tocardo International BV, 2011)

Tocardo aqua 2800: Tocardo Aqua 2800 (Fig. 16) is developed by Tocardo International BV (2011) based in Netherlands. Tocardo Aqua devices are horizontal axis, consisting of 2-bladed fixed pitch rotor and permanent magnet direct drive generator with no gear box. These devices are capable of producing power in both directions of water flow and can operate as single unit or in connection with grid (Tocardo International BV, 2011).

Tocardo International has developed T50 and T150 units for river and inshore applications, while T500 is for offshore applications. T50 is a 50 kW device with 2.8 m rotor diameter and operates at current velocity of 3.5 m/s. T150 is a 150 kW device with 4.5 m rotor diameter and operates at current velocity of 3.5 m/s. T150 can be installed in rivers, retro-fitting in barrages and post-hydro installation. T500 is available in diameter sizes ranging from 7 to 20 m, it produces 500 kW with a rotor diameter of 10 m at current velocity of 3 m/s (Tocardo International BV, 2011).

Davis hydro turbine: Davis Hydro Turbine (Fig. 17) is developed by Blue Energy (2011) based in Canada. The device is a vertical axis turbine, consisting of four fixed hydrofoil blades with 125 kW output. The blades are connected to a shaft that drives a variable speed generator. The turbine can operate through entire tidal range, cut-in speed is 1 m/s. The system can be combined in arrays of up to 4 units (Blue Energy, 2011).

Encurrent turbine: EnCurrent turbine (Fig. 18) is developed by New Energy Corporation Inc (2011) based

Fig. 17: Davis hydro turbine (Blue Energy, 2011)

Fig. 18: Encurrent turbine (New Energy Corporation Inc, 2011)

Fig. 19: Enermar (kobold) turbine (Ponte di Archimede International, 2011)

in Canada. The devices are vertical axis, based on the design of Darrieus windmill. New Energy has successfully developed 5, 10 and 25 kW units and work is underway on 125 and 250 kW units. The devices are designed for rivers, manmade canals and tidal currents (New Energy Corporation Inc, 2011).

Enermar (kobold turbine): Kobold turbine (Fig. 19) is developed by Ponte di Archimede International (2011) S.P.A. based in Italy. Kobold turbine is a vertical axis turbine, with 5 m blade height and diameter of 6 m. Turbine rotation is independent of the direction of incoming current. The device is self-starting and has a high starting torque. The blade pitch is controlled for enhanced rotor performance (Ponte di Archimede International, 2011).

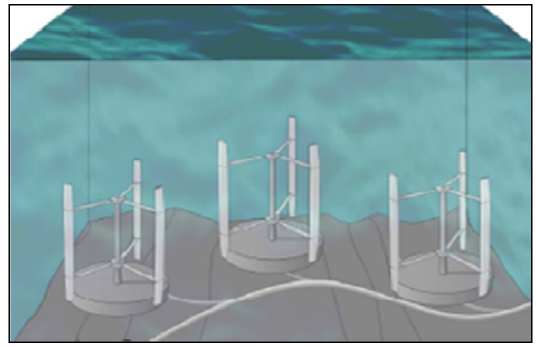

Fig. 20: Current power turbine (Current Power, 2011)

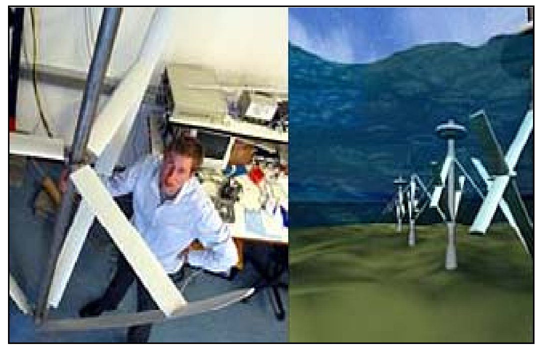

Fig. 21: Wave rotor turbine (Ecofys, 2011)

Current power: Current Power turbine (Fig. 20) is developed by Current Power (2011) AB based in Sweden. The device is designed for placement on ocean or river bottom. The device is a slow-speed, vertical axis turbine which employs a direct drive permanent magnet rotating generator. The device is result of efforts by Division of Electricity, Uppsala University. A 5 kW, 10 rpm, prototype variable speed generator has been extensively tested for further development (Current Power, 2011).

Wave rotor: Wave Rotor (Fig. 21) is developed by Ecofys (2011) (Subsidiary of Econcern) based in Netherlands. Ecofys creatively combined two types of rotors on a single axis of rotation. This assembly can convert tidal current energy as well as wave energy into electricity. The latter is based on the fact that waves are

Fig. 22: Pulse hydro turbine (Pulse Generation Ltd., 2011)

Fig. 23: Stingray (Baker *et al*., 2002)

made of circulating water particles. The assembly consists of a Darrieus rotor with almost vertical (or slanted) rotor blades and a Wells rotor with radial blades. The kinetic energy from tides and waves is directly converted to rotational energy, used to drive a generator and does not require any conversion steps. The device is simple, light and robust with little surface area exposed in sea which decreases structural loads in extreme conditions. The scaled model of the device was tested in NaREC (UK) in 2004 (Ecofys, 2011).

Pulse hydrofoil: Pulse Hydrofoil (Fig. 22) is developed by Pulse Generation Ltd (2011) based in United Kingdom. The device is a vertical axis turbine, designed for optimum performance in shallow water. The Pulse Hydrofoil vertical axis design is different from conventional vertical axis turbines since blades are horizontal rather than vertical, to eliminate the water depth concern for blade length. The device is fully submerged during operation and blades can be folded down to base into survival position during extreme

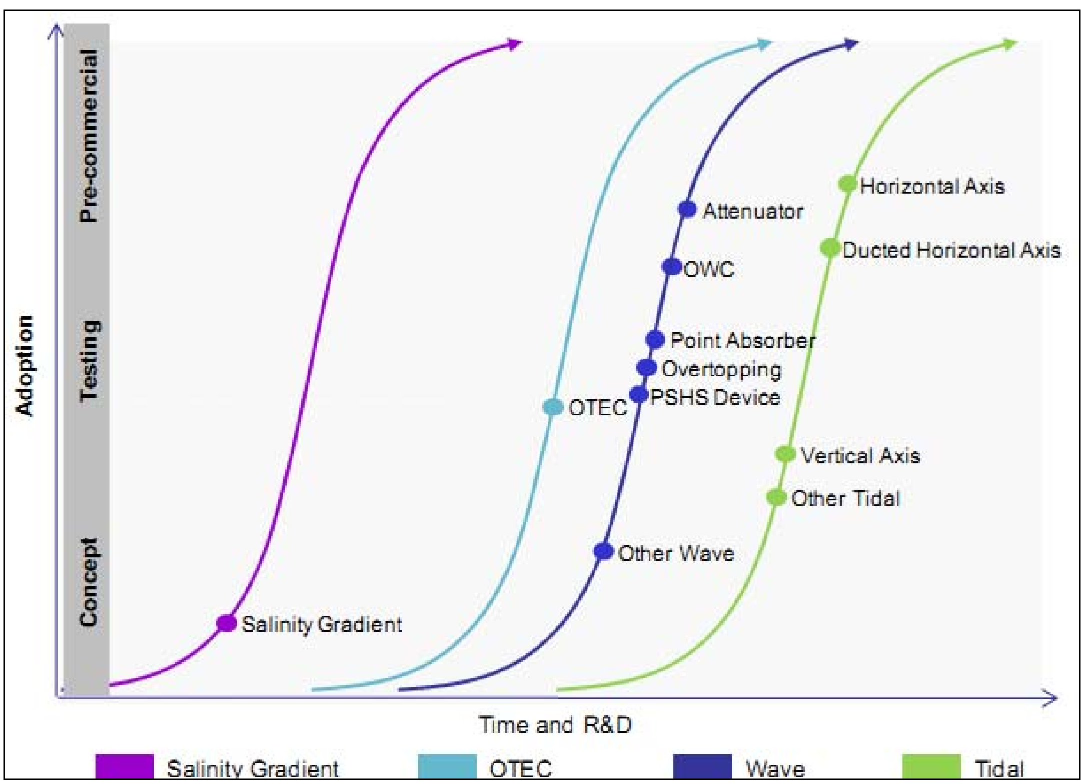

Fig. 24: Ocean energy technology maturity (IHS, 2010)

weather conditions. Pulse Generation Ltd successfully deployed the prototype in the Humber estuary in Northern England in April 2008. Pulse Generation Ltd successfully installed 100 kW "Pulse-Stream 100" near Humber river in the UK at a depth of only 9 m. PS100 began electricity production in May 2009 for Millenium Chemicals (Pulse Generation Ltd, 2011).

Stringray: Stingray (Fig. 23) is developed by The Engineering Business Ltd based in United Kingdom. The technology is based on converting kinetic energy of tides to hydraulic power. The device consists of a hydroplane with an angle of attack, designed to oscillate, which forces hydraulic cylinders to extract and retract. These motions generate high pressure on oil, used to drive a generator to produce power. Stingray devices have a gravity based foundation and normally installed in depths to 100 m. The Engineering Business Ltd successfully deployed its first 150 kW prototype device in September 2002 in UK. The Engineering Business Ltd is currently working on its 3 MW pre-commercial unit (Baker *et al*., 2002)

Present status of ocean energy development: The ocean energy is gaining popularity as regulators focus on regulations to control emissions. IHS presented a detailed evaluation of ocean energy in Global Ocean Energy Markets and Strategies: 2010-2030. Figure 24 illustrates the maturity of ocean energy technologies with respect to oceans energy resources. Tidal current technologies are being explored extensively and horizontal axis turbines are most focused and increasingly popular.

IHS also reported on the participation of countries in developing ocean energy conversion systems where UK is leading the way, shown in Fig. 25. Ireland, France, Portugal, South Korea and Australia are also making their way forward towards ocean energy utilization. The energy markets in these countries will remain industry's primary focus for the next decade (IHS, 2010). The

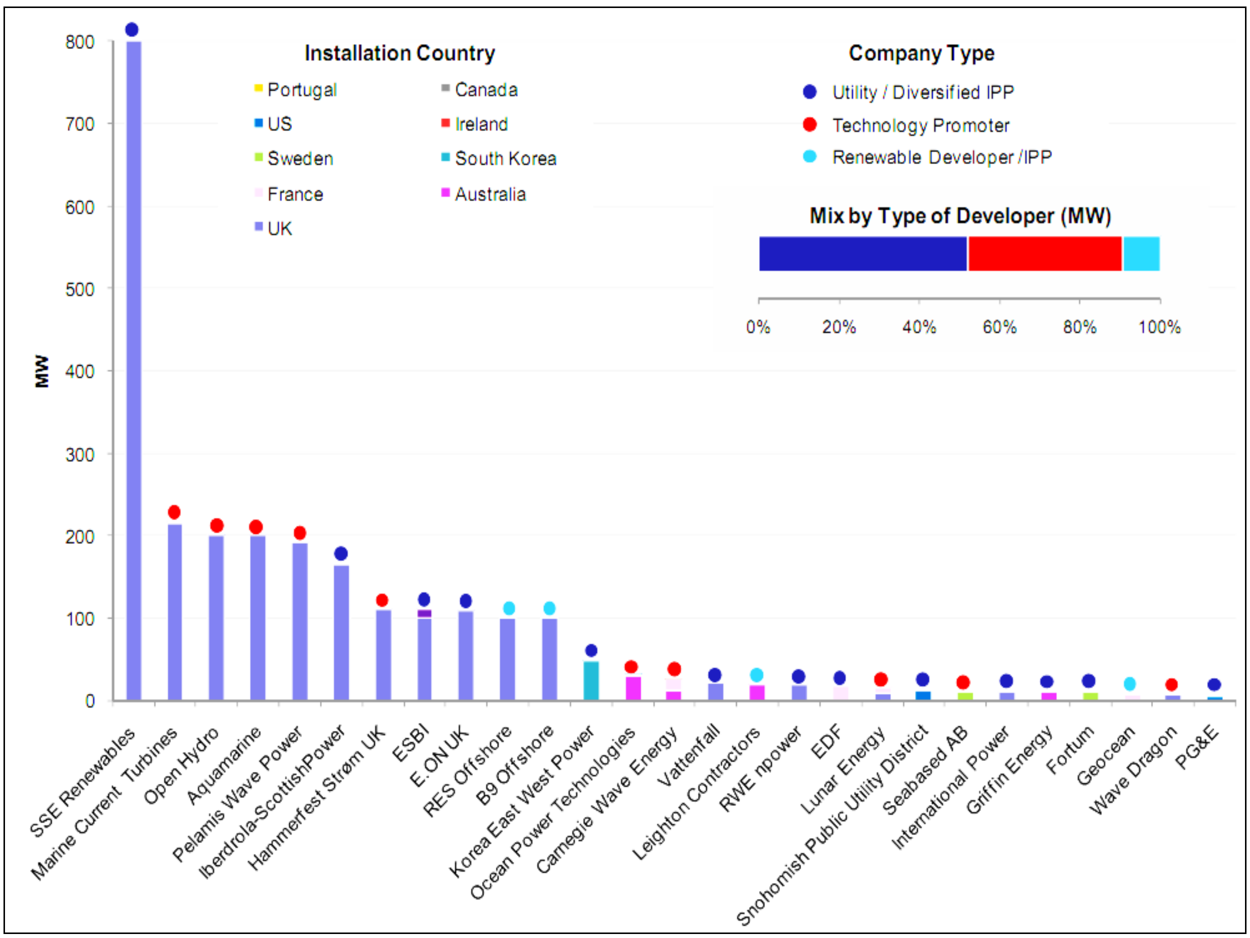

Fig. 25: Ocean energy maturity pipeline by developers and participating countries (IHS, 2010)

regulators have key role in world's way forward towards cleaner energy.

CONCLUSION

The study has presented an in-depth review of harnessing ocean energy by tidal current technologies. Due to depleting fossil fuel resources, their rising cost and adverse environmental effects; the world is obligated to find alternate energy resources. These alternate energy resources should ideally be renewable with minimal environmental effects. The necessity and potential of tidal current technologies were presented. Tidal current technologies are answer to mankind's worst fears of energy resources depletion and devastating destruction of environment. The study also discussed tidal current turbine components and its design parameters. The study presented popular tidal current technologies being used today.

The author also reported present status of ocean energy development. The ocean energy is gaining popularity as regulators focus on emissions regulations. Tidal current technologies are being explored extensively and horizontal axis turbines are most focused and increasingly popular. UK is leading the way in utilizing ocean energy. The regulators have key role in world's way forward towards cleaner energy.

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